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SPACECRAFT DESIGN OPTIMIZATION USING TAGUCHI ANALYSIS

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Reliable, readily available, and affordable space transportation systems have become the key to the success of future space missions. Congressional budget constraints and rising international competition dictate the need to design and build space systems at low cost even with increased performance, reliability and quality requirements. This implies that new philosophy, technology and advanced statistical tools must be employed to design and produce reliable, high quality space systems at low cost.

The quality engineering methods of Dr. Genichi Taguchi, employing design of experiments, are important statistical tools for designing high quality systems at reduced cost. Taguchi methods have been used successfully in Japan and the United States in designing reliable, high quality products at low cost in such areas as automobiles and consumer electronics. However, these methods are just begining to see application in the aerospace industry.

Taguchi methods provide an efficient and systematic approach to optimize designs for performance, quality, and cost. The objective is to determine the optimum levels for the controllable design parameters such that the system is functional, exhibits a high level of performance under a wide range of conditions, and is robust to noise factors.

Studying the design variables one at a time or by trial and error until a first feasible design is found, is a common approach to design optimization. However, this usually leads to either a very long and expensive time span for completing the design or a premature termination of the design process due to budget or schedule pressures. The result in most cases, is a product design which is far from optimal.

In contrast, the Taguchi method utilizes orthogonal arrays from design of experiments theory to study the design parameters simultaneously and their interactions. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. Furthermore, the conclusions drawn from a small scale of experiments are valid over the entire experimental region spanned by the control factors and their settings.

The Taguchi method reduces research and development costs by improving the efficiency of generating information. As a result, development time can be shortened significantly and, important design parameters affecting operation, performance, and cost can be identified.

This research effort utilized the Taguchi method for a weight optimization study for a lunar aerobrake. Aerobrakes are devices which use atmospheric drag instead of propulsion system thrust to modify the velocity and trajectory of a space vehicle.

Aerobraking is proposed for both Mars orbital insertion and for Earth orbit insertion following Lunar or Martian missions. The main advantage of aerobrakes is the significant reduction expected in propellant required as compared to a lunar/Mars orbit insertion using all propulsive braking. Yet, to date, there has been little structural evaluation or design of lunar/Mars aerobrakes to justify further consideration. The objective of this study was to identify viable minimal weight candidate lunar aerobrake structures, and those structural design parameters which have the most profound effect on the final structure weight.

The Taguchi method was utilized to study several simultaneous parameter level variations of an lunar aerobrake structure to arrive at the lightest weight configuration. Finite element analysis was used to analyze the unique experimental aerobrake configurations selected by the Taguchi method. The approach consisted of the following steps:

1. Identify the design parameters and their alternative levels,
2. Define the possible interactions between these parameters,
3. Select an appropriate Taguchi orthogonal array,
4. Create a linear graph and determine the parameter arrangement,
5. Conduct the matrix experiment using finite element analysis,
6. Create a response table and analyze the data,
7. Determine optimum levels for the design parameters,
8. Predict the performance under these levels and verify.

Using the above approach, important design parameters affecting weight and global buckling were identified and the lowest weight design configuration was selected. The study resulted in significant weight savings as compared with the initial (baseline) design configuration. Given the high cost of launching cargo into orbit, the weight reduction realized can result in large savings in cost.

Overall, the results suggest that Taguchi approach to design optimization is a powerful tool which can offer simultaneous improvements in performance, engineering productivity and cost.